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Optoelectronic Technology Consortium

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[PRECOMPETITIVE CONSORTIUM FOR OPTOELECTRONIC INTERCONNECT TECHNOLOGY]

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OPTOELECTRONIC TECHNOLOGY CONSORTIUM

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April 1 to June 30, 1992
Honeywell, Inc.

1.0 Introduction.

The Optoelectronic Technology Consortium has been established to position U.S. industry as the world leader in optical interconnect technology by developing, fabricating, integrating and demonstrating the producibility of optoelectronic components for high-density/high-data-rate processors and accelerating the insertion of this technology into military and commercial applications. This objective will be accomplished by a program focused in three areas.

> Demonstrated performance: OETC will demonstrate an aggregate data transfer rate of 16 Gb/s between single transmitter and receiver packages, as well as the expandability of this technology by combining four links in parallel to achieve a 64 Gb/s link.
>
> Accelerated development: By collaborating during the precompetitive technology development stage, OETC will advance the development of optical components and produce links for a multiboard processor testbed demonstration.
>
> Producibility: OETC's technology will achieve this performance by using components that are affordable, and reliable, with a line BER$<10^{-15}$ and MTTF$>10^{6}$ hours.

Under the OETC program Honeywell will develop packaged AlGaAs arrays of waveguide modulators and polymer based, high density, parallel optical backplane technology compatible with low-cost manufacturability.

The packaged AlGaAs modulator arrays will consist of a single fiber input, a 1x4 fanout circuit, four waveguide modulators, and four fiber outputs, all mounted on a ceramic header. The primary benefits to this approach are enhanced system reliability, particularly at high temperatures, and a device design that is highly producible due to the inherent process tolerance. Combined with the demonstrated high density of these devices when fabricated in arrays, this allows the development of compact and reliable transmitter components.

The objective of the polyimide backplane development effort is to demonstrate a practical high density (>20 lines or channels per mm) parallel optical backplane facilitating (bandwidth x length/power) interconnect figures of merit between one and two orders of magnitude greater than would be attainable with state-of-the-art electrical interconnects. The effort will address both development of an ultimately manufacturable and environmentally tolerant optical backplane, and the optical interface concepts required for practical board-to-backplane optical connection. The key functionalities, and compatibility with standard multiboard assembly practices will be demonstrated in a laboratory evaluation system.

Technical progress achieved during the current reporting period, and plans for the next reporting period, are summarized in the following sections.

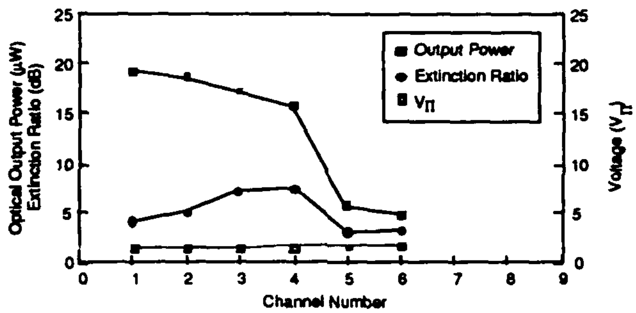
2.0 Progress Summary.

2.1 AlGaAs Modulator Array Development. Task leader: Dr. Mary Hibbs-Brenner

During the previous reporting period, we drew several conclusions from the initial experiments and adjusted our baseline approach as a result. The current approach includes the use of multi-mode interference splitters to direct a single input beam to an array of four modulators, and the use of a doped p-i-n epitaxial structure to reduce the voltage required to drive the device. In the current reporting period, we have completed three fabrication runs with a new mask set (5359) designed to evaluate different splitting designs, different methods of recombining the light in the two arms of each Mach-Zehnder, and different electrode lengths. Three runs with a total of 11 different samples, from 6 different wafers have been fabricated with this new mask set, allowing us to accumulate some information on the reproducibility of our process. Major conclusions include the following:

- A 1x4x8 multi-mode interference (MMI) splitter is more reproducibly low loss than either a 1x8 MMI splitter, or a conventional splitter. The designation "1x4x8" refers to a double staged splitter, which initially splits a single channel into four, and then splits each of those four into two more for a total of eight. A 1x8 MMI splitter is a single stage splitter, which goes directly from one channel to eight. The conventional splitter consists of a series of 1x2 low angle splitters. The results, averaged over a total of 6 different samples, are that the excess insertion loss (over and above the intrinsic splitting loss) ranged from 0.6 to 2.3 dB/channel for the 1x4x8 MMI splitter, from 3.2 to 5.2 dB for the 1x8 MMI splitter, and from 0.2 to 5.6dB for the conventional splitter.

- MMI combiners also produce lower loss than conventional, low-angle combiners. While our previous mask set allowed us to evaluate splitter designs, we did not include any variation in the structures used to recombine the light in the two arms of each Mach-Zehnder interferometer. The current mask set included several arrays of four modulators, with two of the four utilizing 2x1 MMI combiners, and the other two utilizing conventional, low-angle combiners. The diagram in Figure 1 contains a plot of the optical throughput power, extinction ratio and drive voltage when voltage is applied to each arm of a four element Mach-Zehnder modulator array, one arm at a time. Only six channels are shown, since the fourth modulator was not functional. The first four channels used MMI combiners, while the fifth and sixth used conventional low-angle combiners. A clear difference in output power and extinction ratio is observed between channels 1-4 and 5-6. Figure 2 shows plots of L-I curves for two modulators, one with an MMI combiner and one with a conventional combiner. The designations NL, NA, TE and TM correspond to the case where no light is input into the modulator, no polarization analyzer is put into the output, an analyzer is used to look at the TE mode, and an analyzer is used to look at the TM mode, respectively. In the modulator with an MMI combiner, the gradual variation in TM mode with voltage indicates some polarization rotation probably due to metal-induced stress. The low contrast ratio of the TE mode in the modulator with the conventional combiner indicates depolarization perhaps induced by the imperfect apex of the combiner. In general, the conventional combiners resulted in a loss about 2-4dB greater than the MMI combiners.



	Channels 1 – 4	Channels 5 – 9
Output Power	20.2 ± 1.7 μW	6.2 ± 0.7 μW
Vπ	1.85 ± 0.01 V	2.01 ± 0.13 V
Extinction Ratio	6.88 ± 1.82 dB	3.8 ± 0.1 dB
Bias Voltage	2.75 ± 0.29 V	2.75 ± 0.35 V

Figure 1. Optical output power, extinction ratio and voltage required to achieve the full modulation depth as a function of electrode number in a four modulator array. (Each modulator has two electrodes.) The fourth modulator was not operational. However, the results are representative of the arrays tested. Channels 1-4 correspond to modulators with an MMI combiner, while channels 5-8 correspond to modulators with a conventional combiner.

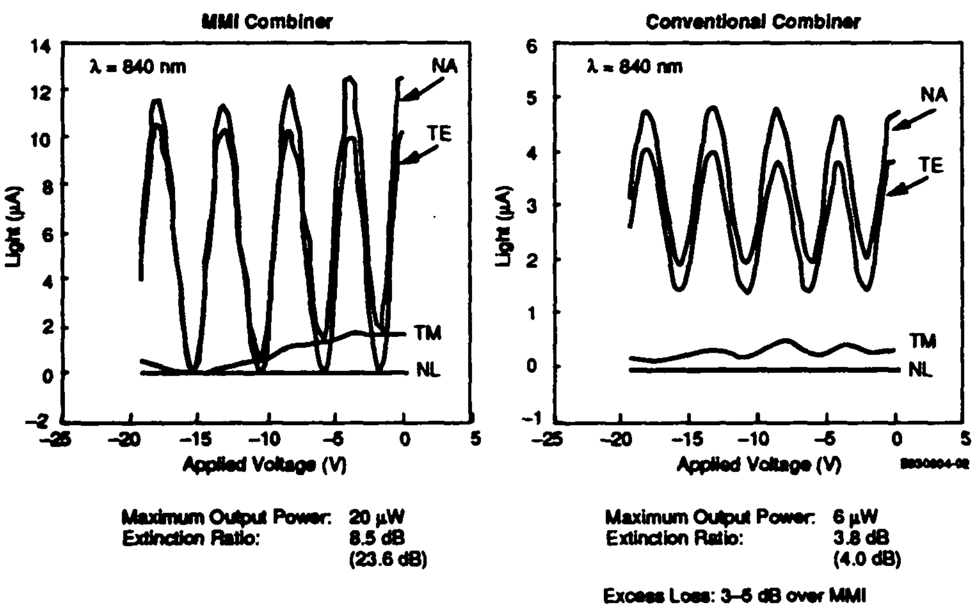


Figure 2. Light transmitted versus applied voltage for a) a modulator with an MMI combiner. b) a modulator with a conventional combiner. NL means no light is coupled into the modulator, NA means no polarization analyzer is used at the output, TE means a polarization analyzer allows the TE mode to be transmitted, and TM means the polarization analyzer allows the TM mode to be transmitted.

- It appears that the use of plated metal contacts will be necessary to reduce stress which degrades the contrast ratio. While this result should be viewed with some caution, since it is based upon only two samples, it appears that significantly improved contrast ratios can be achieved when plated metal contacts are used. We believe that degraded contrast ratios are due to polarization rotation in the channels which is induced by stress. The use of plated metals will be considered baseline for future mask sets and process runs.

- The voltage length product required to achieve a π-phase change within the modulator was found to be in the range of 20-25 V-mm. This is in contrast to our report last quarter of results ranging from 7 to 15 V-mm. However, it is still a significant reduction compared to the previous results from undoped structures of around 50 V-mm, since it allows us to reduce the modulator length by a factor of two. Upon re-examining results from the last reporting period, we noticed that the L-I curves showed anomalous behavior, with the extinction ratio varying erratically with voltage. We therefore conclude that imbalances in the splitting ratios from the conventional splitters, and stress from the metals may have produced these anomalous results. However, we are fairly confident of the current periods results, since the L-I curves were much more well-behaved, and there was a great deal of reproducibility from sample to sample and run to run.

- Uniformity of output power and drive voltage appears to meet the specifications. While more effort will be carried out on future runs to quantify this more carefully, it appears that the output power uniformity using MMI splitters and combiners is generally within 1 dB, and certainly within 3dB in all cases. The variation in drive voltage within a modulator array is usually better than 10%. Less uniformity is observed in extinction ratio, although here it is perhaps more appropriate to specify only that the extinction ratio must exceed a certain value. An extinction ratio of 10dB or more should be sufficient.

- The best array fabricated to date possessed the following characteristics: 1) an excess on-chip insertion loss of -6.7 dB per channel, contrast ratios ranging from 11.2 to 23.5 dB, a voltage length-product ranging from 20.8 to 21.7 V-mm, and a range of 0.6dB in optical power output uniformity.

2.2 AlGaAs Modulator Array Packaging. Task leader: Mr. John Lehman

During the current reporting period we have focused our efforts on designing the bias tee network for the modulator and the substrate on which the modulator, modulator driver and bias tee will be bonded. We have selected and ordered the surface mount capacitors used in the bias tee and as de-coupling capacitors and the thin film silicon resistor arrays used in the bias tee. Initial tests were begun to characterize the cumulative optical coupling losses in our packaging design. We have also evaluated a thermoplastic material as the adhesive material holding the fiber in alignment.

The mechanical and electrical components of the modulator package design are mostly complete. The package will use an alumina substrate for the single mode fiber (SMF) input bonding platform, the AlGaAs modulator array, and the silicon v-groove output fiber assembly Active polishing will be used to thin the SMF bonding platform to the appropriate height based on the thickness of the AlGaAs modulator chip as discussed in earlier reports. Active alignment and a stable, low shrinkage, low CTE epoxy is used to achieve best optical coupling and to fix the SMF. Active alignment and epoxy is also used at the output where multimode fibers aligned in silicon v-grooves collect the modulated light from the AlGaAs waveguide channels. The bias tee network, which allows us to include a DC bias along with the high frequency drive voltages from Martin Marietta's driver chip, has been designed and is being fabricated on ceramic. The selection of filter elements and values was based upon simulations done at Martin Marietta. The optical subassembly, the bias tee and the driver chip are all bonded directly to the heat spreader. The heat spreader is AlN with a metal layer on top. The metalized heat spreader is also used as a ground plane for electrical reference. The heat spreader is bonded to the lead frame. A diagram of some of the critical packaging components is shown in Figure 3. The bias tee and package fabrication are currently under way and expected to be completed by the beginning of September.

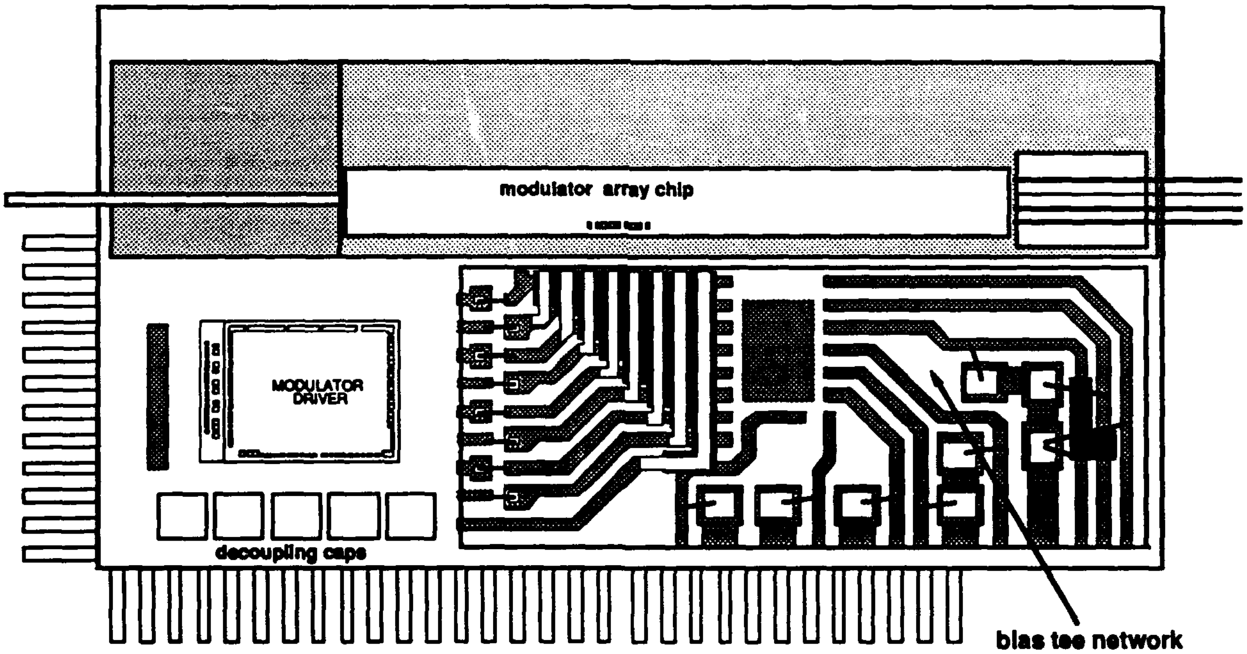


Figure 3. A schematic diagram of the modulator package incorporating the modulator array, single mode fiber input, multimode fiber outputs, modulator driver chip and bias tee network.

Initial tests were completed on a fully optically packaged AlGaAs modulator chip (single mode fiber coupled to waveguide, waveguide coupled to multimode fiber array). The unit showed good thermal stability up to 60C. Accurate coupling loss measurements could not be made due to insufficient information on the AlGaAs waveguide channel attenuation and splitter losses of the particular sample. By the next reporting period a complete characterization of the coupling losses will be performed.

We completed fabrication of special alumina optical submounts with built-in heating resistors under the SMF bonding platform so we could try thermoplastics as an adhesive to fix the fiber once it has been aligned. Thermoplastics would be attractive as a bonding material because the curing time is short relative to epoxies. Single mode coupling was attempted while heating the platform to reflow the thermoplastic but coupling could not be maintained while cooling after the procedure probably due to thermal expansion effects.

2.3. Polymer Backplane Development. Task leader: Dr. Julian Bristow

During the reporting period, we have focused our efforts on fabrication of the fixtures for the board and backplane level elements of the board-to-backplane connector. Our baseline design for the board-to-backplane connector employs a single half-gradient index lens pair connecting arrays of waveguides using expanded beam techniques. Fixtures locate the gradient index lenses to both the boards and the backplanes. We have now fabricated fixtures for location of the gradient index lenses to the boards and backplanes. The fixtures allow passive location of the gradient index lenses with respect to terminated waveguides at the board edge. Each fixture pair consists of an element locating both a lens and a 45-degree prism, and a second element containing only a lens. In both cases, the lenses concerned are half-gradient index lenses derived from commercially available optics. Figure 4 shows the fixtures. The fixtures have been produced from a machinable ceramic. For full scale production, the ceramic fixtures would be molded and processed using established techniques similar to those employed in the manufacture of ferrules for fiber optic connectors.

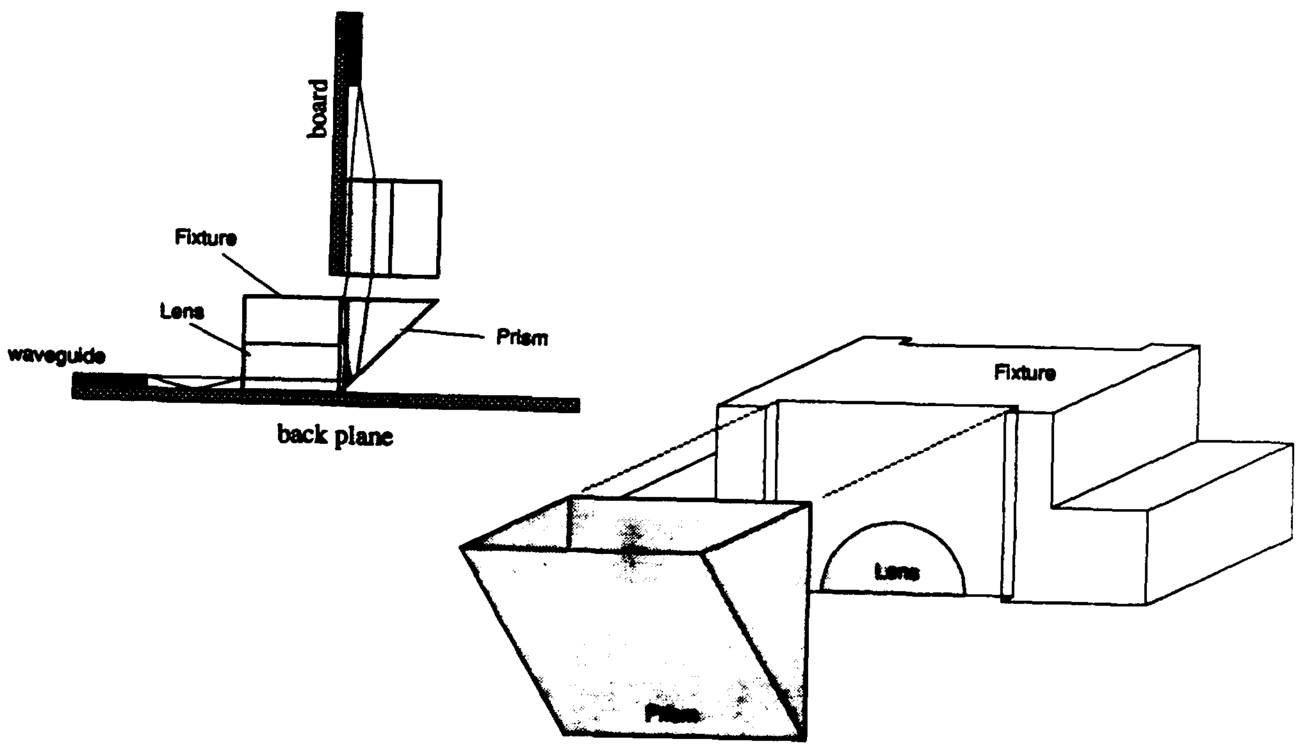


Figure 4. A diagram of the fixture being fabricated to provide alignment between polymer waveguides, grin lens for expanded beam connectors and 45° coupling prism.

3.0. Fourth quarter plans.

3.1. AlGaAs Modulator Array Development.

In the next quarter, we will layout a new mask set consistent with the currently identified best approach, i.e. the use of a 1x4x8 MMI splitter, a 2x1 MMI combiner for recombining the two arms of each Mach-Zehnder interferometer, and plated metal electrodes. The mask set will also include some variations in metal electrode length to ensure compatibility with the driver circuits. Air bridge metal technology will be used to connect the modulator electrodes to bond pads at the edge of the chip. One fabrication run with this mask set should be completed by the end of the next quarter. The resulting chips can then be optically and electrically packaged together with the driver chips.

3.2. AlGaAs Modulator Array Packaging.

During the next reporting period we will assemble a complete optical package (i.e. single-mode input, multimode output) on the same submount and do a complete evaluation of coupling losses at room temperature and the additional losses induced when the ambient temperature is varied. We will complete fabrication of the full-up electrical and optical ceramic packaging components and will establish the assembly procedures for die attach, wire bonding and alignment of the optical interfaces within the module. With these tasks complete, and upon receipt of the modulator driver chip, we will be prepared for assembly of a mechanical mock-up of the complete modulator module.

3.3. Polymer Backplane Development.

During the next quarter we plan to complete the layout of the backplane and board level waveguides for the polymer backplane demonstration.

4.0. Summary.

In the current reporting period we have made significant progress in improving contrast ratio, insertion loss and array optical power output uniformity. The uniformity and reproducibility of drive voltage has been established. The current baseline of 1x4x8 MMI splitters, 2x1 MMI combiners and plated metal electrodes has been identified as that most likely to produce the best optical power output uniformity, highest contrast and lowest insertion loss of the approaches considered. This approach is expected to result in modulator arrays meeting all of the specifications during the next quarter.

The package design is nearly complete, and will be fabricated by the end of the next quarter. Single mode fiber to modulator to multimode fiber packaging will be carried out and coupling losses measured. Performance of the optically packaged modulators over a range of temperatures will be evaluated.

In the polyimide demonstration, a fixture for aligning polyimide guides to grin lens to 45° reflector prism has been designed and fabricated. In the next quarter we will complete layout of the backplane and board level waveguides for the polymer backplane demonstration.